BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Discussion of Differences in RCS Propellant Budgets between Apollo "C" Mission and AAP Missions 1, 3A and 3 - Case 610

DATE: May 22, 1968

FROM: K. E. Martersteck

ABSTRACT

The RCS propellant budgets for the Apollo "C", AAP-1, 3A and 3 missions have been compared. Essential differences between the Apollo and AAP missions exist which result in substantially larger RCS budgets for the AAP missions. Unlike the Apollo "C" budget which is tightly constrained by spacecraft RCS tank capacity, the AAP budgets provide for dispersed trajectories, off-nominal systems performance and crew errors during maneuvers, a larger contingency for changes in plan after mission initiation and experiment support. In addition since the AAP missions will be flown in higher-altitude circular orbits, almost four times as much backup RCS retro propellant is required compared with Apollo "C", which is specially adjusted to minimize the backup retro needed.

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MEMORANDUM FOR FILE

I. GENERAL COMMENTS

At first glance the Apollo "C" Mission and AAP CSM Missions 1, 3A and 3 appear to be rather similar. In each case a CSM is inserted by a Saturn IB into low-altitude Earth orbit, performs a coelliptic rendezvous and various other orbital operations and finally reenters the atmosphere returning the crew to earth.

There are, however, several essential differences which must be pointed out. First the Apollo "C" mission is a demonstration of CSM operations. That is, this first manned Apollo mission will consist of a series of relatively independent tests to establish the capability of the spacecraft, crew and MSFN support facilities to conduct an earth orbital mission.(1) On the other hand, the primary objectives of the AAP missions are to conduct long duration missions with the Orbital Workshop and to obtain scientific data about the sun using the LM/ATM, etc.(2 3) Without completion of maneuvers such as rendezvous, these AAP missions will be total failures. Thus the AAP mission planners must take care to ensure that sufficient propellant is available to ensure successful execution of requisite maneuvers despite off-nominal conditions.

Secondly, the Apollo "C" mission is constrained to conduct Earth orbital tests using the spacecraft designed for lunar missions and RCS tanks sized accordingly. Therefore it has been necessary to extensively massage and tweak the mission profile to prevent RCS propellant requirements just for the "nominal" (i.e. perfectly-executed) maneuvers from burgeoning beyond current tank capacity. In contrast the AAP mission objectives, rather than a specific tank limitation, dictate RCS propellant requirements. The AAP RCS budget is largely based on available Apollo data and analyses tempered by man-in-the-loop simulations and Gemini experience, all combined to produce the best estimate of the propellant quantities necessary to accomplish the mission objectives under nominal or off-nominal conditions.

Finally, it should be noted that the AAP CSM's are about 5000 pounds heavier than the Apollo spacecraft at corresponding phases throughout their respective missions.

II. COMPARISON OF RCS BUDGETS

Table I lists a summary by comparable mission phase of the RCS propellant budgets for Apollo "C" mission and AAP-1, 3A and 3. Apollo data were taken from Reference 4, while AAP data came from the budget prepared by the Mission Operations Office, AAPO, MSC dated April 23, 1968. Remarks pertinent to specific mission phases are given below.

TABLE I

RCS BUDGET (LBS)

Mission Phase	Apollo "C" Mission (S/C 101)	AAP-1	AAP-3A, 3
Pre-launch Checks	4.4	4.4	4.4
Separation from S-IVB	65.5	24.5	24.5
Rendezvous			
Pre TPI (phasing, etc.)	153.2	125.4	125.4
TPI thru TPF	265.1	455.0	455.0
Orbital Operations			
Satisfy test objectives	284.7		
Station keep and pre-dock inspection of OWS		48.0	48.0
Dock to MDA		30.0	30.0
Experiment support and cluster attitude hold		350.0	500.0
Reentry Operations	52.3	51.1	51.1
RCS Backup Deorbit	320.0	1230.0	1230.0
Contingency	61		
15% of pre-deorbit		161	186
2 x RSS of 1σ's plus backup retro 1σ		449	449
Gaging Error Allowance	78	220	220
TOTAL USABLES REQUIRED	1284.2	3148.4	3323.4

A. Separation from S-IVB

Included in this phase of the Apollo "C" mission is propellant for simulated docking and S-IVB fly-around as well as station keeping for SLA photography.

B. Rendezvous

All missions considered here include a coelliptic rendezvous from an orbit 10 nm below the target. Man-in-the-loop simulations at McDonnell Douglas Corporation (MDC) have shown that for the rendezvous terminal phase (TPI through TPF) with perfect initial conditions, the mean propellant consumption is 250 pounds.(5) With mean dispersions at TPI included in the simulations, the mean terminal phase propellant consumption increases to 552 pounds. The Apollo "C" mission rendezvous budget (256.1 pounds), which is based on the MDC data, has no apparent allowance for trajectory dispersions or crew errors. Of course, in the Apollo "C" mission if the rendezvous deviates from the nominal profile, it can be abandoned with relatively little impact on the remainder of the mission. However, the AAP rendezvous must be successfully completed or the entire mission is lost.

Using in-house simulation data, MSC AAPO and G&C Division analyses of coelliptic rendezvous with $\Delta h = 10$ nm predict the mean terminal phase Δv to be 112 fps* ($1\sigma = \pm 24$ fps). Thus a mean propellant consumption of 455 pounds ($1\sigma = \pm 97$) has been budgeted for the AAP CSM's based on the MCS in-house results. It is noteworthy that this AAP rendezvous RCS budget (mean + 1σ) compares very favorably with the MDC prediction when dispersions are considered.

C. Orbital Operations

All Apollo "C" propellant requirements not specified under other mission phases have been lumped here.

Included under AAP "Orbital Operations" are a total of 78 pounds for maneuvers associated with docking to the MDA. Apollo "C" has no comparable requirement.

The quantities budgeted under AAP "Experiment Support and Cluster Attitude Hold" have been agreed upon between MSFC and MSC for planning purposes at this time. No detailed breakdown for the use of this propellant is available yet. Potential needs on AAP-1 are cluster slewing and attitude hold for Earth applications experiments and backup or augmentation for the Workshop Attitude Control System (WACS) for the 28-day mission. Potential needs on AAP-3A are similar to AAP-1 except that the mission duration is 56-days. AAP-3 RCS may be needed for CMG momentum dumping or attitude hold in case of CMG pointing control system failure in addition to the contingencies listed for AAP-1. The propellant capacity on AAP-3 must also reflect possible contingency requirements of the CSM/LM backup mission for AAP-3/AAP-4.

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*The theoretical minimum Δv for the terminal phase is 42 fps.

D. RCS Backup Deorbit

Because of the mission demands on Apollo "C" RCS and the limited tank capacity, the trajectory has been adjusted so that the RCS backup deorbit burn will be made only at apogee of the 220 x 90 nm orbit. This reduces the backup deorbit requirement to Δv = 108 fps or, equivalently, 320 pounds of propellant. The Apollo "C" prime deorbit system (SPS) is capable of deorbit from any point in the orbit.

The AAP mission duration and experiment require operations at a higher circular orbit. Therefore the backup retro system must have essentially the same capability as the primary system. The Δv for retro from a 220 nm circular orbit is 340 fps which results in 1230 pounds being needed for the AAP spacecraft.

E. Contingency

In the AAP budget there are two categories under contingency. An allowance of 15% of the pre-deorbit propellant is made to accommodate potential changes in the mission after it has begun. To provide for possible systems off-nominal performance and/or crew errors, twice the root sum square of the 1σ estimates (except backup retro) is budgeted. Because of the importance of backup retro, a 1σ = 155 pounds based on 86% efficiency (instead of a nominal 97%) is added to the 2 x RSS of the other 1σ values.

The Apollo "C" mission contingency allowance is simply the difference between the amount budgeted for various mission phases and the usable propellant capacity. The 61 pounds currently budgeted is about 7.5% of the pre-deorbit propellant.

F. Gaging Error Allowance

The PVT dispersion errors are treated identically in both Apollo and AAP: a 3σ gaging error allowance of 6% of total usable propellant capacity is included in each budget. For AAP planning 3600 pounds has been assumed as the usable capacity.

III. CONCLUSION

The RCS propellant budgets for the Apollo "C", AAP-1, 3A and 3 missions have been compared. The budget for the currently planned Apollo mission appears to be very tight. Virtually no allowance has been made for off-nominal performance. In the preparation of the AAP budget, an attempt has been made to utilize all applicable simulation data and analyses to project reasonable propellant requirements. Provision has been made for dispersions, crew errors and contingencies. Such an approach seems prudent at this time.

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K. E. Martersteck

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References

(1) Mission Requirements "C" Type Mission, CSM Operations, Revision 1, 15 January 1968, NAS 9-4810

(2) AAP Directive No 3C, Flight Mission Directive for AAP-1/AAP-2, Dated January 3, 1968 (with change 1 Dated May 14, 1968

(3) AAP Directive No 5, Flight Mission Directive for AAP-3/AAP-4, Dated February 12, 1968

(4) Apollo Mission C (AS-205/CSM-101) Spacecraft Reference Trajectory, Volume IV - Consummables Analysis, MSC Internal Note No 68-FM-96, April 17, 1968

(5) McDonnell Douglas Corporation Apollo Flight Crew Support, Apollo Design Note No 8, October 27, 1968

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